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Fiber Reinforcement of Polyurethane Foam

By B. G. Parker

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Final Report

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The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

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SUMMARY

This project was initiated to determine the mixing requirements for the addition of fiber fillers to urethane foam and to evaluate the effects these fibers have on the physical properties of these foams.

The addition of wollastonite fibers was accomplished by simply adding them to one of the foam components. The addition of glass and carbon fibers required prior mixing of the foam components, then final mixing of the foam and fibers. Other methods of mixing resulted in incomplete mixing of the foam resin.

The incorporation of fibers in rigid urethane foam generally gave reduced brittleness and improved compressive strength up to levels of 5 percent fiber filler. Above 5 percent fiber content the physical properties were reduced.

Surface-treated wollastonite fibers in flexible urethane foam gave some increase in the 10 percent compression strength, but gave little or no improvement in tensile strength.

DISCUSSION

SCOPE AND PURPOSE

Fiber reinforcement of polymers has resulted in higher strengths and improved thermal properties. The purpose of this project was to evaluate the requirements for adequately incorporating fibers in urethane foam formulations, specifically to determine the mixing requirements for addition of glass, graphite, and wollastonite fibers in two urethane foam formulations. In addition, the effects that fiber addition has on urethane foam properties were determined. The effects on the mechanical strength of rigid urethane foam and the tear strength of flexible urethane foam also were determined.

PRIOR WORK

Recent developments in the use of fiber reinforcement of polymeric materials have resulted in higher strengths and improved thermal properties. Some examples are reinforced reaction injection-molded polyurethanes for automotive applications and glass fiber reinforced isocyanurate-urethane foam used for backing of asphalt roofing. Some of the fibers currently in use are glass, wollastonite, graphite, and proprietary mineral fibers.

Surface treatment of these fibers with coupling agents provides better adhesion or compatibility between the resin and fiber, resulting in increased mechanical properties, easier dispersion of the fiber, and improved processibility.

ACTIVITY

Preparation of Test Specimens

Five fiber fillers were chosen for evaluation: glass, carbon, and three types of wollastonite (Table 1). Wollastonite is a naturally occurring calcium metasilicate. The grade chosen for evaluation has an aspect ratio (length-to-diameter) of 20:1 and an average diameter of 3.5 μm. Wollastonite is a primary replacement for asbestos and is listed as non-hazardous under Federal Toxic Substances Control Act listing number 10101-39-0. These fibers were used for reinforcing two foam formulations, a rigid structural foam, shown in Table 2, and a flexible foam, shown in Table 3. All foam samples were prepared in a density of 320 kg/m^3 (20 lb/ft^3) and up to levels of 15 percent by weight fiber filler.

Table 1. Fiber Fillers

Material	Type	Length	Surface Treatment
NYAD G	$CaSiO_3$	70 μm	None
Wollastokup 1100.05	$CaSiO_3$	70 μm	A-1100
Wollastokup KR 55.05	$CaSiO_3$	70 μm	Ken React -55
M-8610	Glass	0.6 cm	Z6032
Thornel VMA	Carbon	0.6 cm	None

Table 2. Rigid Urethane Foam Formulation

Material	Type	Amount (pbw)
R Component		
LS 490	Polyether Polyol	100
H_2O	Water	0.75
DC 197	Surfactant	1.00
TMBDA	Catalyst	1.20
T Component		
PAPI	Polymeric Isocynate	152

Table 3. Flexible Urethane Foam Formulation

Material	Type	Amount (pbw)
R Component		
PG 8528	Polyether Polyol	77.3
P 581	Polymer Polyol	22.7
H_2O	Water	1.44
Quadrol	Crosslinker	
DC 1	Catalyst	0.25
T Component		
MRS 10	Polymeric	30.5
TDI	Diisocynate	7.5

Addition of the wollastonite fibers was relatively easy. The fibers were added to the R component and thoroughly mixed. The T component was then added and mixed like a normal foam system and poured into preheated molds.

The addition of glass and carbon fibers was more difficult. The glass fiber was treated with N-β-(N-vinyl benzylamino)ethyl-γamino propyl trimethoxy silane. The carbon fiber was Thornel VMA. The process of adding these fibers to the R component resulted in inadequate mixing of the R and T components. The resulting foam contained areas rich in polyol and isocyanate, caused by fiber clogging of the conn blade mix head. The most successful method of mixing was to first mix the R and T components, then add the glass or carbon fibers, and mix. Foam samples were molded in 21.25 by 21.24 by 2.54 cm preheated aluminum molds. All rigid foam blocks were cured at 163°C (325°F). The flexible foam was cured at 82°C (180°F) for 8 hours.

Three types of wollastonite fibers were chosen for evaluation. The first one selected was NYAD G, which has an aspect ratio (L/D) of 20:1. NYAD G is a pure wollastonite fiber containing no surface treatment. The two other types of wollastonite fibers were chosen to evaluate the effects of surface treatment of the fiber with coupling agents. Wollastokup 1100.05 and Wollastokup KR 55.05 were chosen. Wollastokup 1100.05 is the same as NYAD G fiber treated with 5 percent by weight of A-1100 silane coupling agent (gamma-aminopropyltrimethoxysilane). Wollastokup KR 55.05 is composed of the NYAD G fiber treated with 5 percent by weight of (tetra (2,2-diallyloxymethyl-1 butoxy)-titanium di(di-tridecyl) phosphite).

<u>Compression Tests</u>

Test specimens 2.865 cm in diameter and 2.54 cm in height were machined from foam blocks. Compressive strength and compressive moduli were determined at a 0.025 m/m crosshead speed perpendicular to foam rise. The results are shown in Table 4. All of the results shown are normalized to a density of 320 kg/m^3. Figure 1 shows the effects of changing filler level on the compressive strength. The wollastonite fibers gave some improvement in compressive strength up to 5 percent by weight, then began showing reduced strength. The glass and graphite fibers both show reduced strengths.

<u>Brittleness Tests</u>

An alternate test method was developed to test thin sections of rigid foam for brittleness. Samples were machined to 1.25 by 0.32 by 5 cm. The samples were placed in a fixed torsional fixture on a mechanical spectrometer with a specimen height in the fixture of 2.5 cm. The torsional force required to break the sample was then measured. The results are shown in Figure 2. The fillers tended to give some added strength at 5 percent filler level, then began to show reduced strength.

<u>Flexible Foam Tests</u>

Compression deflection was determined on the flexible foam samples at 10 and 50 percent compression. The data obtained from these tests are given in Table 5. The results are further shown in Figures 3 and 4. At 10 percent compression, there is some increase in compressive strength with the wollastonite fibers that

Table 4. Compressive Properties of Fiber-Filled Rigid Urethane Foam

Filler	Percent (by Weight)	Compressive Strength* (MPa)	Compressive Moduli* (MPa)
None	-	7.72	224
1100.05	5	7.74	244
1100.05	10	6.96	232
1100.05	15	5.58	158
NYAD G	5	7.93	264
NYAD G	10	7.49	265
NYAD G	15	7.26	266
KR 55.05	5	7.91	255
KR 55.05	10	7.85	272
KR 55.05	15	7.66	264
Glass	5	6.31	219
Glass	10	4.85	184
Glass	15	5.18	184
Carbon	2.5	5.72	169
Carbon	5	7.69	240

*Average of three values.

had been treated with a surface modifier. All other fillers show reduced strength. At 50 percent compression, the glass and graphite fillers show some initial increase in strength, but the general trend is that increasing the fiber filler content results in reduced strength. Tensile test specimens were machined from the flexible foam blocks to 0.63 cm thick by 1.27 cm wide. The results of these tests are also shown in Table 5. The addition of fiber fillers results in reduced tensile strength of the flexible foams.

ACCOMPLISHMENTS

The effects of incorporating several fiber fillers in both flexible and rigid polyurethane foams were evaluated. Incorporating small amounts (less than 5 percent) of fiber filler that has been treated with surface adhesion promoters results in an increase in mechanical strength. In addition, a torsional test method was developed for evaluating the brittleness of thin-section rigid urethane foam.

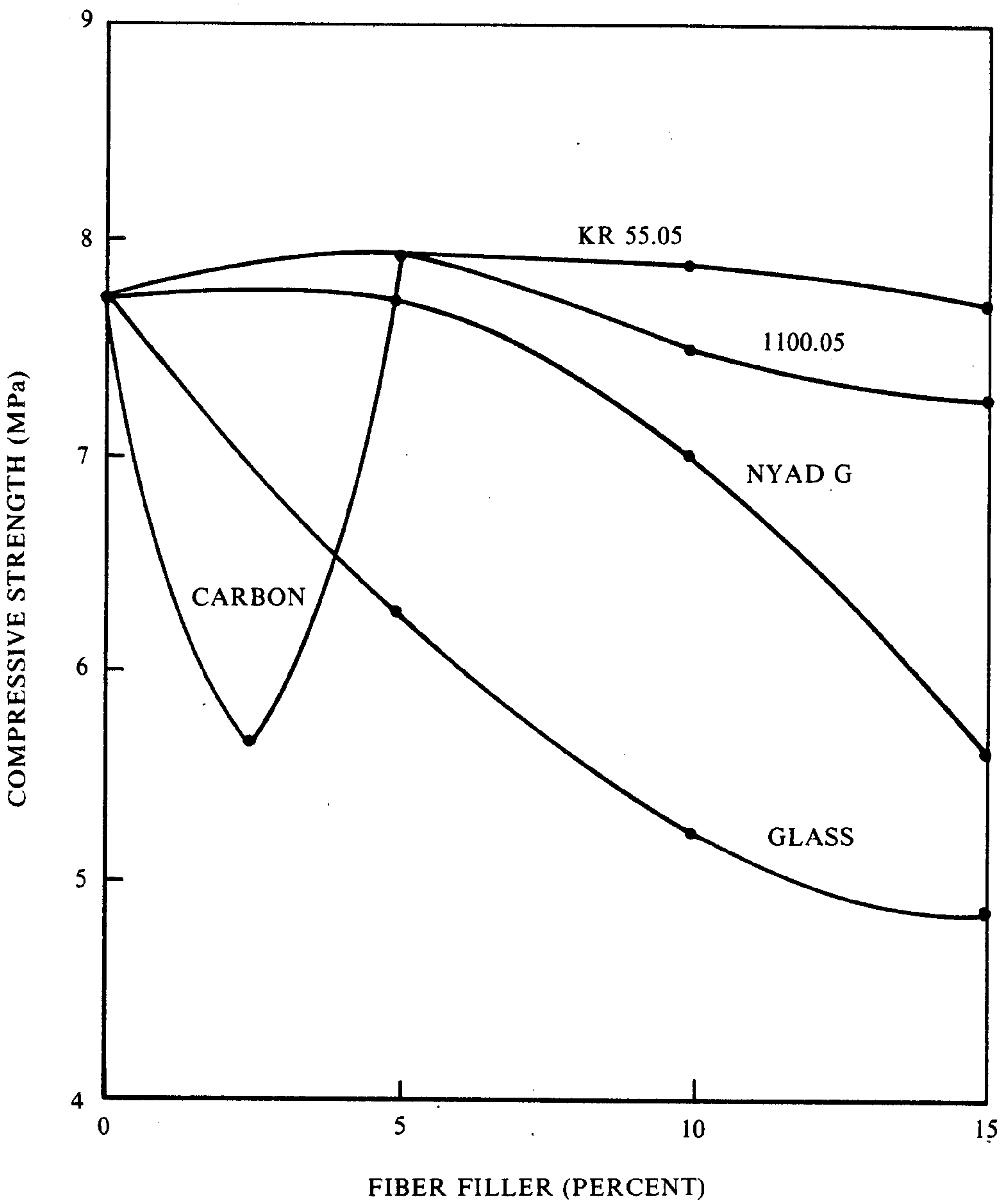

Figure 1. Effect of Fiber Filler on Rigid Foam Compressive Strength

FUTURE WORK

Although the fibers evaluated did not provide a substantial increase in compressive strengths of the foam system, additional fibers may be developed in the future which may improve strengths.

Table 5. Effects of Fiber Filler on Flexible Urethane Foam

Filler	Percent (by Weight)	Compression Deflection* (kPa) 10 Percent	50 Percent	Tensile Strength (kPa)
None	-	197	607	793
1100.05	5	200	552	448
1100.05	10	220	629	758
1100.05	15	214	643	731
NYAD G	5	176	566	669
NYAD G	10	153	549	517
NYAD G	15	174	560	641
KR 55.05	5	190	580	751
KR 55.05	10	199	567	634
KR 55.05	15	202	598	807
Glass	5	177	664	676
Glass	10	141	626	745
Glass	15	130	576	324
Carbon	2.5	179	641	421

*Average of three values.

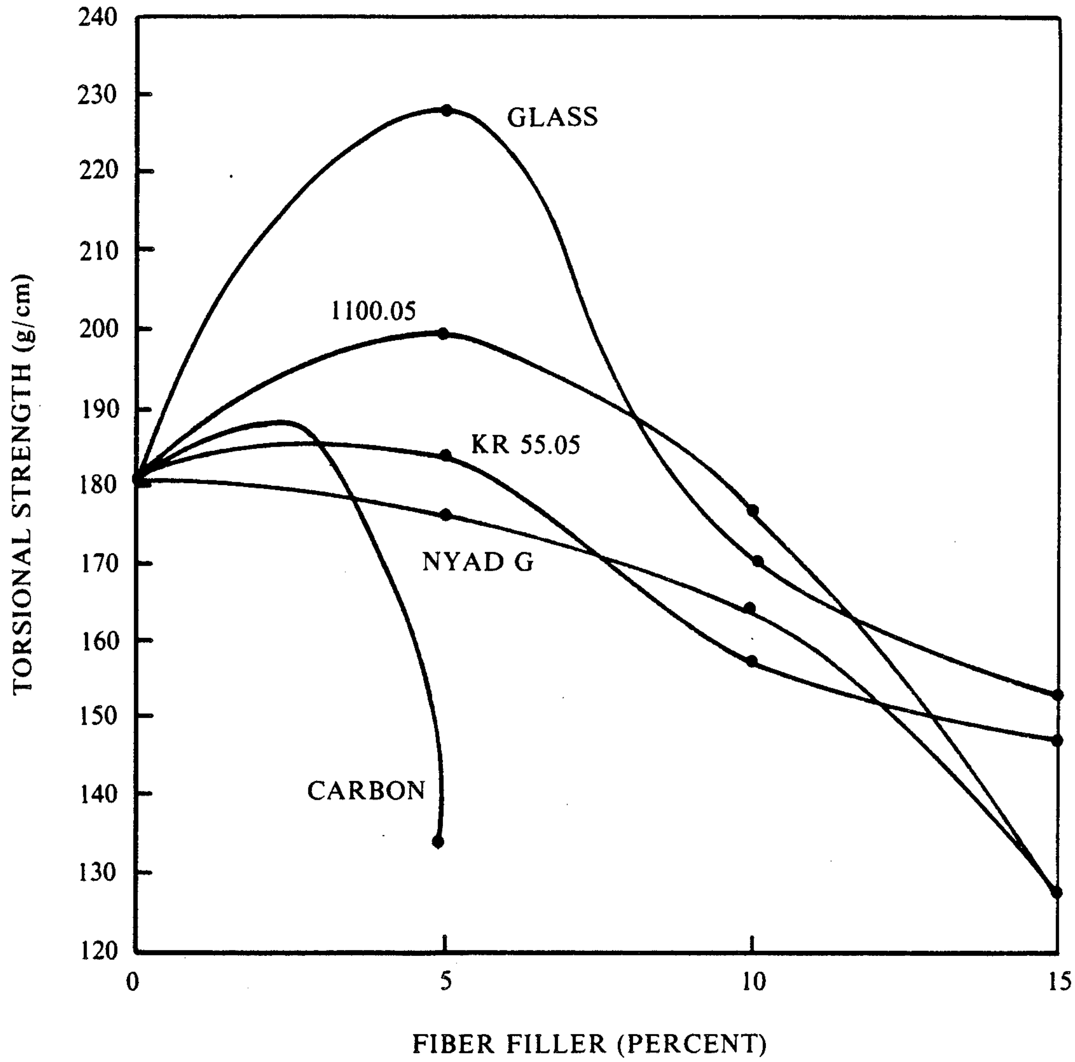

Figure 2. Effect of Fiber Filler on Brittleness of Rigid Foam

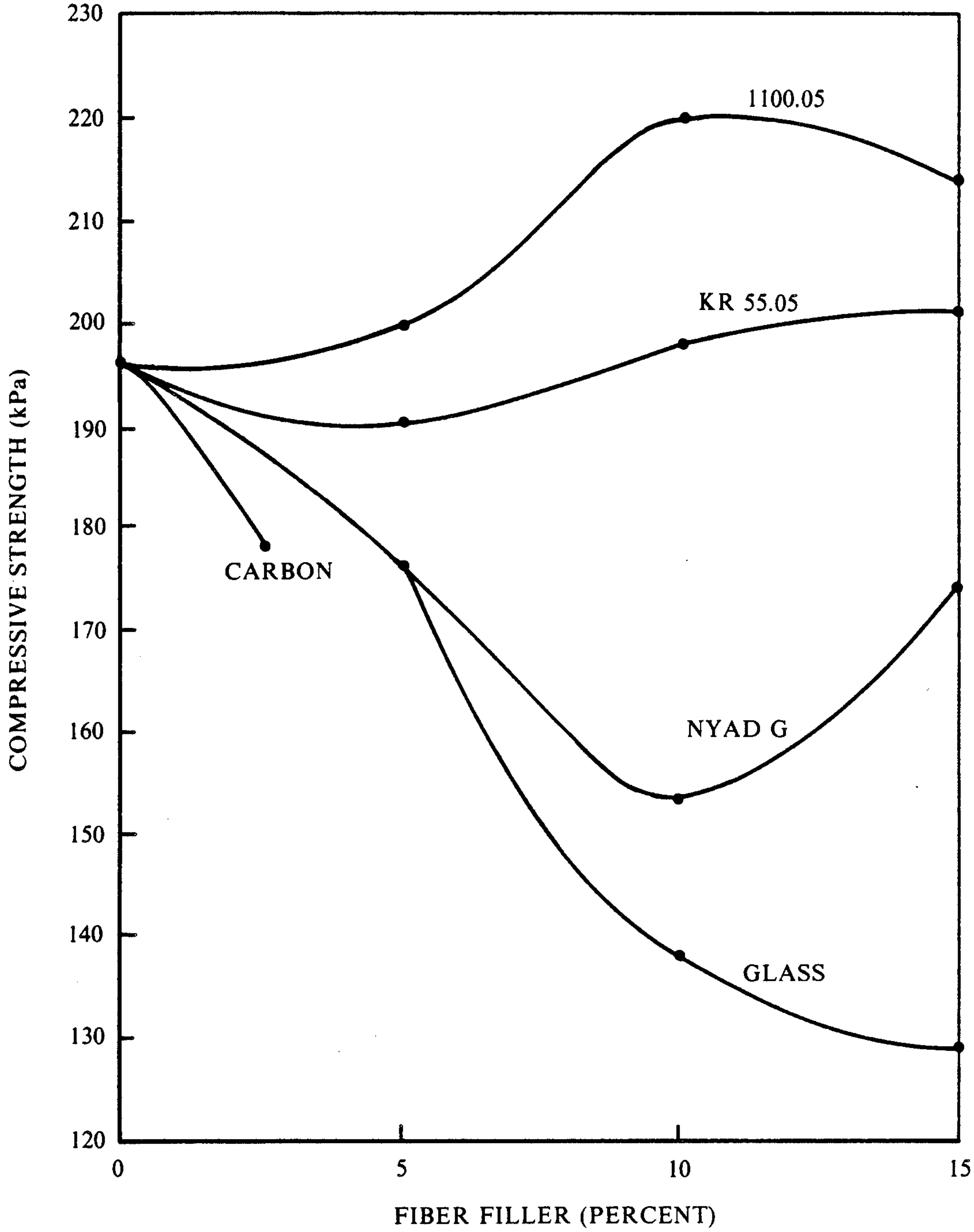

Figure 3. Effect of Fiber Filler on Flexible Foam at 10 Percent Compression

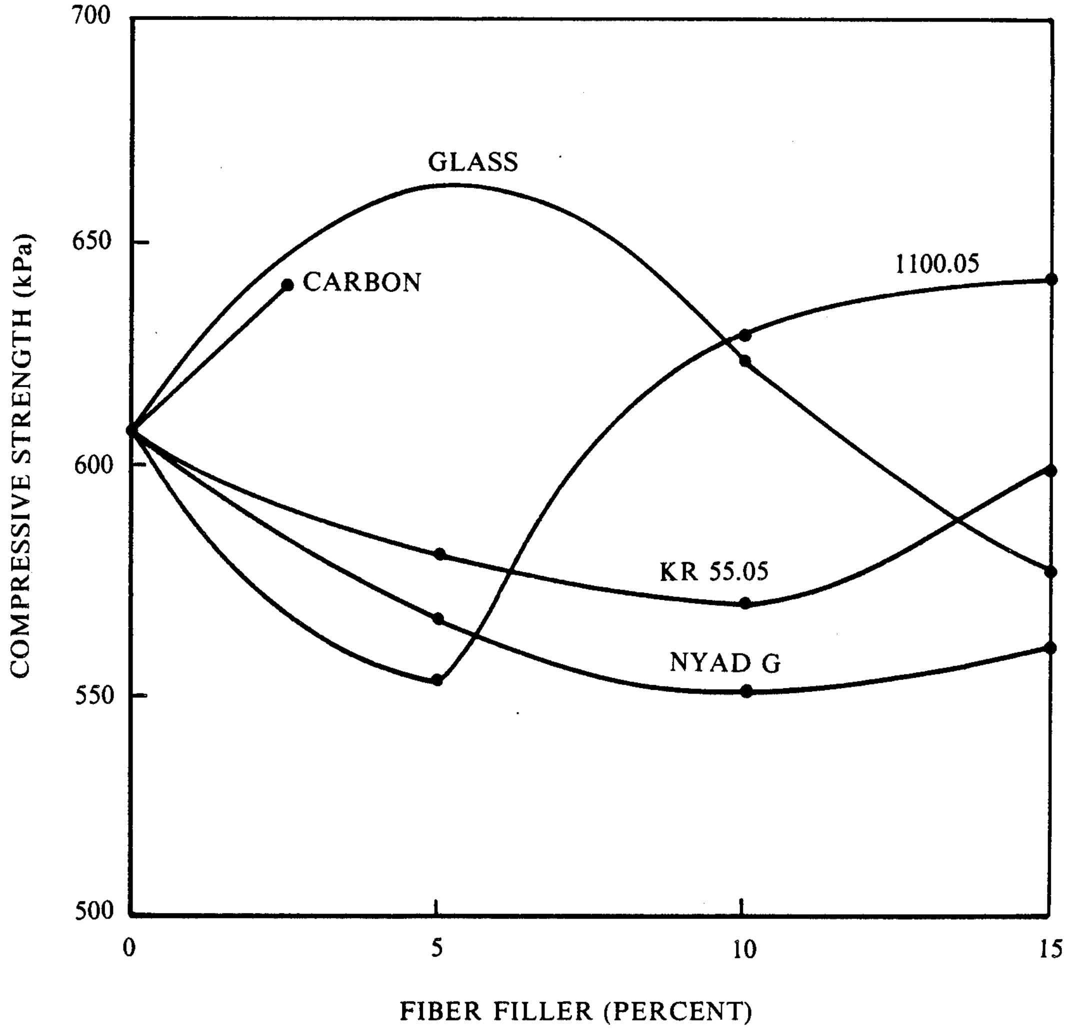

Figure 4. Effect of Fiber Filler on Flexible Foam at 50 Percent Compression

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PLASTICS: Foams

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